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Overview

To meet the enormous future demand for forest products due to anticipated global population growth, not only should we practice sustainable forestry and maximize raw material use and extend useful life of products by means of new technologies, we also need to maximize use of every available fiber resource.

The pulp and paper industry has been continuously searching for alternative fiber resources other than wood for pulp and paper production. The Institute of Paper chemistry in 1976 published an annotated bibliography on "Pulping of bagasse and other papermaking fibers," listing 442 such world wide studies. A more recent example is the successful development of newsprint production from kenaf in the Southwestern United States. Bagasse, a residue of cane sugar production, is an important fiber resource for pulp and paper production in the tropics. Because of lack of forest resources, China heavily depends on rice and wheat straw as the raw material for pulp and paper products.

In the Unites States, an immense public interest in cornstalk paper occurred in the late 1920's. The March 27, 1929 Daily Times of St. Cloud, Minnesota was printed entirely on cornstalk paper. The pulp and paper industry, however, only has been intermittently interested in cornstalks. The main obstacle of using cornstalk for pulp production is its low density and low fiber content. Paper made from the fibrous portion of cornstalk does have properties comparable to paper made from wood fibers, but chemical pulping four tons of cornstalk produces only one ton of fibrous pulp and one ton of pith cells compared to obtaining over two tons of pulp from four tons of wood chips. In the 1940's, chemical pulping of cornstalk was accomplished in two steps. After a brief pulping reaction, pith cells were separated and the fibrous portion was further pulped. The separated pith cells were used as filler for other types of paper or paperboard. Research before World War II concluded that although good paper could be made from cornstalk, it could not be done economically in competition with wood.

A 1994 literature review authored by Youngquist et. al. and published by the Forest Products Laboratory cited 1,165 world wide research reports on the use of agriculture fibers for building materials and panel products during the period from 1913 to 1993. Over half of these studies were published after 1975, and again, bagasse and straw were the most studied materials with 235 and 269 studies cited, respectively. Because the United States has had the luxury of plentiful supplies of wood and wood fibers, we have not seriously considered agriculture residue as a raw material component for building and panel products. In other parts of the world that lack forest resources, agriculture-based building and panel products probably would not be developed in the near future because they need these raw materials for pulp and paper production. At the present time, they can substitute building materials and panel products with other materials, such as metals, concrete, and brick.

At Iowa State University, research on the utilization of cornstalk goes back to the 1920's. For a period over twenty years, Professors Sweeney and Arnold of the Chemical Engineering Department led the research, producing numerous published results. During that time, there was a mill in Dubuque, Iowa, producing insulation fiberboard from cornstalk. The Dubuque fiberboard plant was closed and the ISU research results were shelved in libraries because corn fibers could not economically compete with abundant and superior quality wood fibers. The recent national environmental movement has greatly influenced the supply and price of wood and wood fiber. Harvest from national forests in the Pacific Northwest has been greatly reduced, forcing many sawmills in the region to close and many people to loss their jobs. Hardboard and medium-density fiberboard are normally produced from sawmill residues, but now some plants in the region have to supplement the shortage of wood fibers with wheat straw fibers. The lack of forest resources in Iowa provides an attractive opportunity for the under-utilized agriculture fibers. One of the promising ways to utilize agriculture fibers is to use them in mixture with wood fibers for the production of panel products. With ongoing research in short-rotation woody crop, agroforestry, riparian bufferstrip, and shelterbelt projects in the ISU Forestry Department, it is anticipated that certain amount of woody biomass would be available for such uses. With this future projection, in June 1995 an ISU biomass composite research group initiated a study of wood/agriculture fiber composites. The initial phase of this project is expected to be completed in June 1996. The selection of cornstalk as the agriculture fiber source in this study is quite obvious. Switchgrass also is selected because of its availability in southern Iowa where it is widely grown on the Conservation Reserve Program(CRP) land and because it is used as one of the vegetative components in the establishment of riparian bufferstrips along streams. Some results of the pulping and agriculture/wood composite studies are reported as follows.

General Characteristics of Cornstalk and Switchgrass

The stem of corn and switchgrass consists of three tissue systems, the epidermal, the fundamental, and the vascular. The outer surface of epidermal cells are lined with a specialized layer called cuticle. The cuticle layer is rich in the fatty substance cutin which is relatively hydrophobic and therefore very difficult to be bonded with adhesives. The fundamental tissue, also called ground tissue or pith, is composed of thin-walled and isometric (as wide as long in dimension) parenchyma cells. Vascular bundles containing xylem and phloem scatter within the ground tissue. In cornstalk, vascular bundles are enclosed in a sheath of thick-walled fibrous cells called sclerenchyma (Fig. 1). In switchgrass, sclerenchyma cells form a continuous cylinder just beneath the epidermis, and sclerenchyma also occurs at the outer edge of vascular bundles and in the leaf sheath (Fig. 2). Fibrous sclerenchyma cells are the desirable elements for paper making and panel production. It is evident from Figures 1 and 2 that neither cornstalk nor switchgrass has a high fiber content.

Lignin content is about 15% in cornstalk and 10% in switchgrass, much lower than the average values of 22% for hardwoods and 29% for softwoods. Lignin is a substance in plants that provides the rigidity for mechanical support and helps to bond cells together. A low lignin content is a beneficial attribute if the material is to be used for chemical pulp production because it would take less effort to remove lignin to produce pulp. A high lignin content in the raw material, however, is desirable in the production of hardboard and fiberboard. Hardboard and fiberboard are produced by consolidating thermo-mechanical pulp (TMP) fibers at a high temperature with or without resin adhesives added. During thermo-mechanical pulping, the raw material is first exposed to a temperature over 375 °F to plasticize the lignin-rich middle lamella, followed by separation of fibers along the plasticized middle lamella with a mechanical force. Lignin on the surface of TMP fibers acts as an adhesive when fibers are compressed at temperatures over 375 °F.

Cornstalk and Switchgrass Pulp Properties

Cornstalk and switchgrass were chemically pulped by a sulfate (kraft) process. Comparison of pulping characteristics and pulp properties of cornstalk, switchgrass, a 5-year-old hybrid cottonwood (Crandon), and mature southern pine is shown in Table 1.

Cornstalk has the lowest pulp yield among the four materials studied. The low pulp yield of cornstalk is due to its high content of water-solubles, especially sugars and oligosaccharides. Pulp freeness shown in Table 1 is a measure of fiber coarseness; the finer the fibers, the more difficult it is for the fiber mat to drain water, resulting in a low value of pulp freeness. A high content of pith cells in cornstalk and switchgrass pulps is responsible for their low freeness.

The tensile and burst strength of cornstalk pulp are greater than those of juvenile cottonwood pulp and are comparable to those of southern pine pulp. Cornstalk pulp, however, has inferior tear strength as compared those of both juvenile cottonwood and southern pine pulps. The excellent tensile and burst strength of cornstalk pulp is attributed to good fiber to fiber bonding facilitated by thin-walled pith cells. Cornstalk pulp's inferior tear strength can be attributed to its low fiber content. The switchgrass pulp, on the other hand, has poor tensile and burst strength but has a greater tear strength than those of cornstalk and juvenile cottonwood pulp. Long fibers in switchgrass are responsible for this superior strength property.

Hardboard Properties

Wet-process hardboards containing different mixtures of wood and cornstalk or switchgrass fibers with a target density of 62.4 lbs/ft^3(1 g/cc) were produced. These hardboards were made using 2% phenol-formaldehyde as the binder. The wood fiber furnish used in this study was obtained from Georgia Pacific Corporation's hardboard production plant in Duluth, Minnesota. Cornstalks and switchgrass were collected from central and southern Iowa, respectively, and these materials were ground into fibers with a 12" Sprout Bauer disk refiner under ambient conditions.

Table 2 shows that hardboards made from wood fibers are superior to boards made from cornstalk fibers and that board properties decrease with increasing amount of cornstalk fibers in the board. Similar results are obtained for switchgrass fibers as shown in Table 3. Tables 2 and 3 also show that cornstalk is a better material than switchgrass for hardboard production. The difference between cornstalk and switchgrass fibers may be due to extremely long and tough fibers in corn husk and leaf sheath. As the fiber composition changes, internal bond strength (IB) is the most influenced property, followed by bending (MOR) and tensile strength. Modulus of Elasticity (MOE) or rigidity is not as sensitive to changes in fiber composition. Cornstalk fibers cause more thickness swell of hardboard than switchgrass fibers do. Morphological characteristics of fibers and low lignin content of cornstalk and switchgrass are the main reasons that cause reduction in board properties. Nevertheless, hardboard produced with a mixture of equal parts of wood fibers and cornstalk or switchgrass fibers does not seriously compromise board properties.

A series of hardboards also were produced by using 2% Arpro 2100 soy protein (ADM Products, Inc.) as the adhesive. Results indicate that hardboards bonded with 2% Arpro 2100 have 69% MOR, 93% MOE, 63% IB, 71% tensile strength as compared to those boards bonded with 2% phenol-formaldehyde resin. Thickness swell of hardboards bonded with 2% Arpro 2100 is 20% greater than that of boards bonded with 2% phenol-formaldehyde resin.

Conclusions

Although cornstalk and switchgrass fibers are generally inferior to wood fibers for paper and panel products, these agriculture fibers do have many other potential uses, such as for paper towels, corrugating medium, and insulation board. Agriculture residues also can be the raw material base for energy and chemical feedstock. For energy use, it can either be directly used as a biomass fuel or be converted to ethanol and other gaseous or liquid fuels. Cellulose or dissolving pulp from agriculture residues would produce many useful cellulose derivative products, such as fabrics, photographic films, cellophane, lacquers, plastics, just to name a few. Of course, all these uses are not currently economical. However, the current concept of product life cycle analysis which takes into account the economical and environmental consequences of producing and using various products indicates economics soon will change due to global population growth. When that time comes, many consumer products will have to depend more heavily on renewable resources. Increased use of agriculture residues would be able to contribute to meeting the future raw material demand.

Table 1. Comparison of unbeaten kraft pulp properties of cornstalk, switchgrass, juvenile cottonwood, and mature southern pine

Pulp Properties	Corn stalk	Switch grass	Cotton wood	South Pine
Pulp Chip Density (g/c.c)	0.10	----	0.33	0.54
Fiber Length (mm)	1.90	2.43	1.01	4.00
Pulp Yield (%)	43.8	48.3	52.3	48.4
Freeness (ml)	440	420	575	720
Kappa Number	10	----	16	40
Residual lignin (%)	1.5	----	2.4	6
Tensile Index (kN.m/g)	53.5	31.7	47.3	55.2
Burst Index (kpa.m^2/g)	3.20	2.16	2.71	3.89
Tear Index (mN.m^2/g)	7.13	9.21	7.32	18.50

Table 2. Effect of fiber composition on physical properties of hardboards containing cornstalk and wood fibers bonded with 2% phenol-formaldehyde resin

	Percent Fiber Composition (Corn/Wood[1])				
Property	100/0	75/25	50/50	25/75	0/100
MOR (psi)	3991 (71)[2]	4251 (75)	4604 (82)	4542 (80)	5644 (100)
MOE (1000 psi)	358 (92)	359 (92)	375 (96)	364 (95)	382 (100)
IB (psi)[3]	76 (59)	91 (71)	124 (97)	117 (91)	128 (100)
Tensile (psi)[4]	2528 (73)	2928 (85)	3301 (95)	3215 (93)	3464 (100)
TS (%)[5]	31 (177)	28 (160)	22 (126)	19 (109)	17.5 (100)

[1]Commercial furnish containing 20% softwood and 80% mixed eastern hardwood fibers was obtained from Georgia Pacific Corp., Duluth, MN.

[2]Values in parenthesis are percentages relative to the properties of boards containing 100% wood fiber.

[3]Internal bond strength measured as tensile strength perpendicular to board surface.

[4]Tensile strength parallel to board surface.

[5]Thickness swell after 24 hours soaking in water at room temperature.

Table 3. Effect of fiber composition on physical properties of hardboards containing switchgrass and wood fibers bonded with 2% phenol-formaldehyde resin

	Percent Fiber Composition (Switchgrass/Wood)				
Property	100/0	75/25	50/50	25/75	0/100
MOR (psi)	3496 (62)	3911 (69)	4020 (71)	4935 (87)	5640 (100)
MOE (1000 psi)	307 (80)	323 (85)	318 (83)	353 (92)	382 (100)
IB (psi)	70 (55)	90 (70)	101 (79)	112 (88)	128 (100)
Tensile (psi)	1804 (52)	2593 (75)	2833 (82)	3188 (92)	3464 (100)
TS (%)	25 (143)	19 (109)	17 (97)	16 (91)	17.5 (100)

Figure 1. Transverse view of a cornstalk, showing distribution of vascular bundles (Vb) in ground tissue (Pi, pith). Vascular bundles are enclosed in a sheath of sclerenchyma (Sc). Scanning electron microscopy (SEM), 60X magnification.

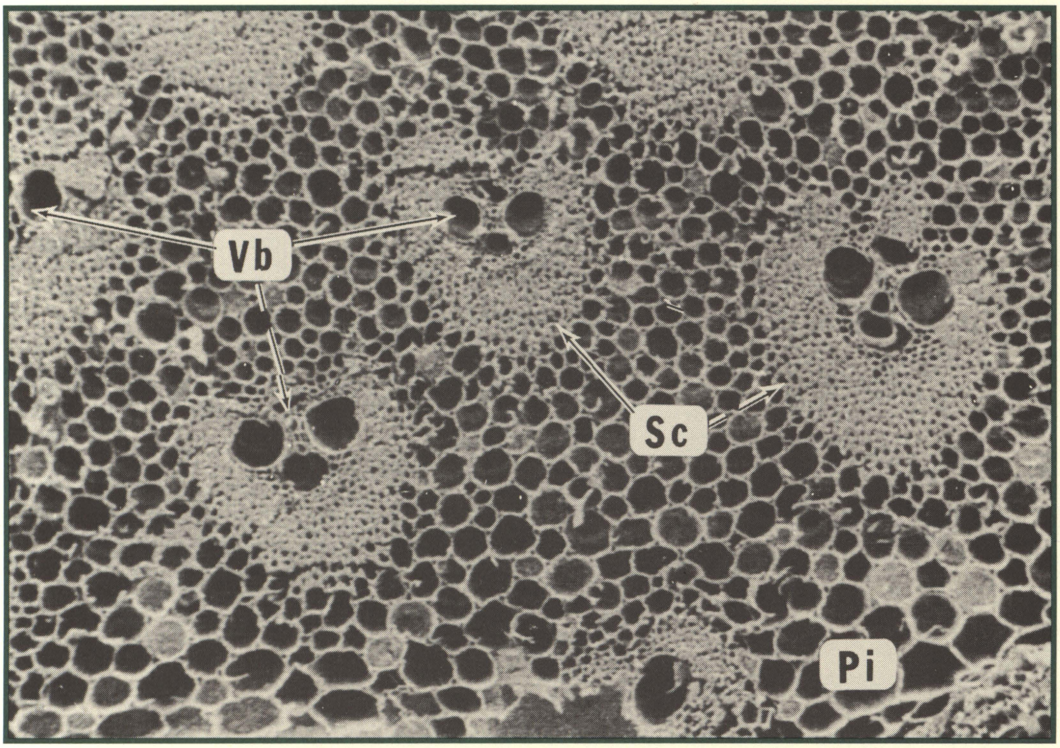
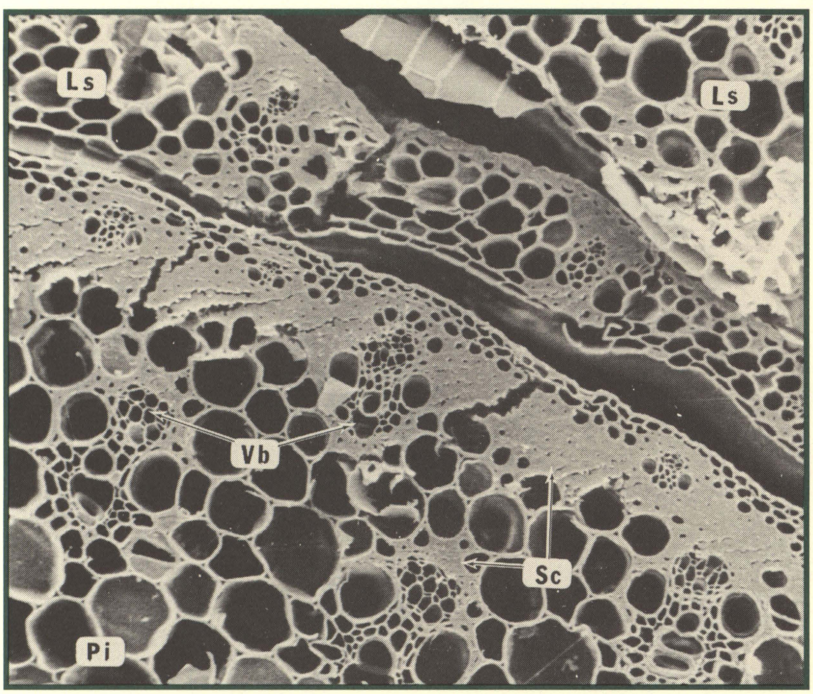
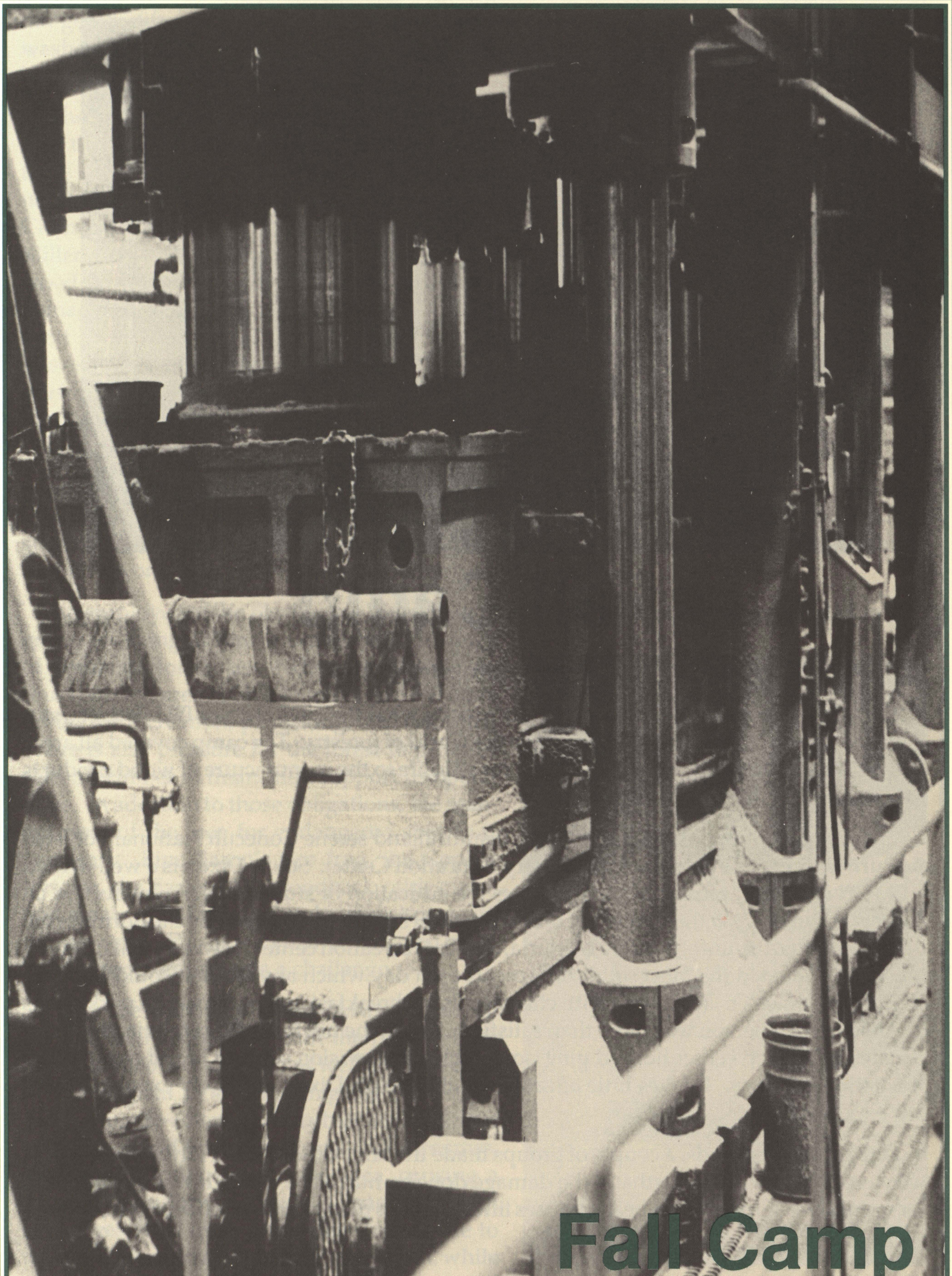


Figure 2. Transverse view of a switchgrass stem, showing distribution of vascular bundles in stem and in leaf sheaths (Ls). Sclerenchyma (Sc) forms a continuous cylinder beneath the epidermis. SEM, 120X.





Fall Camp